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AUTHOR Quinlan, Kathleen M.
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ABSTRACT

The educational beliefs of seven mechanical engineering faculty members at one university were examined in the context of their department and the history of the engineering education. Participants were selected to cover the demographic range across the department. Each of the faculty members was interviewed and observed at two points over the course of an academic year. Interviews focused on course syllabi, course goals, course content and structure, teacher role, perceptions of students, student evaluation, and the instructional development agenda for the course. The mechanical engineering department at the university was fractured between its two major divisions (thermosciences and design), with significant social and intellectual differences between the two. Despite commonalities at one level, key differences were found among: the academics' educational beliefs about the nature of the profession; learning goals for students; teaching approaches; and analysis of student difficulties. Illustrative case examples are included. The paper concludes that the faculty beliefs found in this department of mechanical engineering recapitulate major developments in and professional differences within the field. Implications for research on teaching and faculty development are discussed. (Contains 40 references.) (SM)

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Kathleen M. Quinlan

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Building Bridges: The Scholarly Dimensions of Faculty Beliefs about Engineering Education

Kathleen M. Quinlan
College of Veterinary Medicine
Cornell University

Presented at the annual meeting of the
American Educational Research Association, Montreal, Quebec, April 20, 1999.

Abstract

The educational beliefs of seven mechanical engineering faculty are examined in the context of their department and the history of the engineering education. Despite commonalities at one level, key differences were found among the academics' educational beliefs about the nature of the profession; learning goals for students; teaching approaches; and their analysis of student difficulties. Illustrative case examples are included. It is concluded that the faculty beliefs found in this department of mechanical engineering recapitulate major developments in and professional differences about the field. Implications for research on teaching and faculty development are discussed.

Objective and Conceptual Framework

Educational beliefs play an important role in shaping teacher's choices and actions (Clark & Peterson, 1986; Fox, 1983; Menges & Rando, 1989; Munby, 1982; Pajares, 1992; Prawat, 1992; Prosser & Trigwell, 1997; Quinlan, 1996; Samuelowicz & Bain, 1992; Stodolsky & Grossman, 1996; Trigwell, Prosser, & Taylor, 1994; Wilson, 1990; Wineburg, 1991). In particular, to make changes in educational practice, these researchers conclude that one must change teachers' beliefs. Although the construct of teacher beliefs is critical to teaching enhancement, we still know little about the complexities of the educational beliefs that academics bring to their teaching in higher education.

Pajares (1992) argues that the construct of educational beliefs is "diffuse and ungainly, too difficult to operationalize, too context free." He suggests that "*educational beliefs about* [particular areas of teaching and learning practice] are required . . ." Among these beliefs he notes "educational beliefs about specific subjects or disciplines.. . ." (p. 316) James Calderhead (1996), in an extensive review of the literature on teacher knowledge and teachers' beliefs, references several recent studies of primary and secondary school teachers' beliefs about mathematics, science, English, foreign languages and social studies. Much of this work has grown out of Lee Shulman's (1986) framework of teacher knowledge.

However, studies of beliefs about the subject or the field are strikingly scarce in the higher education literature on academics' beliefs about teaching and learning (for exceptions see: Dinham et al. 1995; Irby, 1994; Lenze, 1996; Quinlan, in press). Yet, the discipline, field or subject matter lies at the root of scholarship in all its forms and is the dimension of academic life with which academics typically identify most strongly (Clark, 1987; Freedman, 1979; Jenkins, 1996; Smith & Geis, 1996; Treisman, 1992). The academics at research oriented universities in particular, are "deeply convinced of the worth of their particular subject matter." (Freedman 1979, p. 42).

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Furthermore, research on teaching in higher education has largely overlooked the *contexts* of teaching and learning. Stodolsky and Grossman, researchers of secondary education, argue, "To understand a particular teacher's practices requires knowing how the teacher views the subject, the students, and the goals. But it also requires knowledge of the context in which the teacher works (school, department, nature of the student body [and the subject matter])." (Stodolsky & Grossman, 1996. p. 76)

Since Ernest Boyer's 1990 monograph, *Scholarship Reconsidered: Priorities of the Professoriate*, interest has been raised in how to define, identify, document and reward the "scholarship of teaching." The notion of scholarship is intimately connected with the system of disciplinary (or professional) communities of knowledge construction, legitimization and transformation (Edgerton, Hutchings, & Quinlan, 1991; Shulman, 1993). The challenge remains to create a discourse and knowledge base about the scholarly dimensions of teaching -- the intellectual substance of pedagogical thought and practice as rooted in the field. To do so requires building bridges between the study of teachers' knowledge and beliefs and the study of disciplinary and professional cultures, histories and contexts.

This paper compares and contrasts the educational beliefs about mechanical engineering held within one department, to study the contextualized, scholarly dimensions of academics' educational beliefs. The academics studied in "Pine University's" (a pseudonym) mechanical engineering department reveal how academics' conceptions of their profession are linked to their educational priorities and the ways in which they analyze their students' performance and construct their teaching practice. By examining these beliefs in the context of the larger history of engineering education, we are also able to appreciate how academics' educational beliefs reflect larger, cultural patterns in the field (Becher, 1994).

Methods and Data Sources

This study is part of a larger, multi-disciplinary project conducted in the United States on academics' beliefs about teaching and departmental faculty cultures. I made site visits to the mechanical engineering department at "Pine University", during which I observed departmental meetings and faculty seminars, sat in on classes and intensively interviewed seven academics about their perceptions of the teaching of their subjects and the local departmental culture (interviewees are referenced in the paper by the initials of their pseudonym). Additional academics were also interviewed to get a broader picture of the faculty culture within the department.

Each of the seven focal academics was interviewed and observed at two different points over the course of an academic year. These seven faculty members were purposively selected to cover the demographic range across the department, including both men and women, members of the two different divisions within the department, and various age groups. As the study was part of a larger project, I selected focal academics who participated in a collaborative, developmental peer review process within the department. Thus, it is likely that these academics were more articulate about teaching and may put a higher priority on teaching than other members of the department who did not volunteer to participate. Thus, they may not be representative of the department as a whole or represent the full range of pedagogical beliefs within the department. The study is more aptly generalizable to

theory (analytic generalization) than to broader populations of faculty or institutions (statistical generalization) (Yin, 1989).

In the first interview, each study participant was asked to talk through the syllabus of one of their courses, discussing their goals, the content and structure, their role as teacher, their perceptions of students and their roles, the evaluation of student work and their instructional development agenda for this particular course. I developed these categories for the interview protocol based on the dimensions found in previous literature on conceptions of teaching (cited above) and on the categories of teaching proposed in work on the peer review of teaching (Edgerton, Hutchings & Quinlan, 1991; Urbach, 1992). The interview was also structured around a particular course in order to ensure that the academics would be describing their teaching beliefs and approaches in the grounded context of teaching a particular subject.

I analyzed the evidence by using a general pattern-matching analytic technique (Yin, 1989) done through an iterative process of data collection, data reduction, data display and conclusion drawing and verification (Miles & Huberman, 1984). In the first iterative phase of anticipatory data reduction (before conducting the interviews), I specified some "bins" for each question into which I expected academics' responses might fall. These categories and bins served as initial guides for data collection and analysis. However, since few other researchers have studied particular subject-specific conceptions of teaching and learning in higher education, I also searched for new, emergent themes in the data.

To do so, I condensed the main points of each interview (12-20 pages) into a 2 to 3 page "memo." Each memo summarized those issues which the academic spoke about the most - by referring to repeatedly during the interview, elaborating on at some length, or speaking about with the most vehement tones. I also selected key quotes which expressed those main ideas most succinctly and eloquently. Through this process, I tried to capture what was most important to each interviewee in his or her own terms. As I wrote the summary memos, I kept notes of the questions that the data answered, in order to distill the main issues across the interviews and determine missing information that needed to be followed up. Using the major questions, I set out the data in a matrix. Studying the matrix, together with the memos and transcripts, I was able to compare each of the faculty member's beliefs with respect to each of the key questions.

The second interview was constructed based on preliminary analyses of the first round of interviews, seeking interviewees' responses to quotes or summaries of key points from previous interviews. The issues culled from the first interviews included: the distinction between analysis and synthesis; the role of projects and labs and teamwork.

The primary purpose of this paper is to prompt a new way of thinking about academic's beliefs about the teaching of their subject matter and to illustrate this conceptual framework by reporting on the scholarly aspects of teaching beliefs in one departmental case study. Individual and shared faculty members' beliefs are examined in the context of a historical look at the discipline and within the context of their university and department. I do not seek to resolve or discuss ways of dealing with each of the particular differences among these academics. To the extent that the case example of the mechanical engineering department at Pine University -- and the individuals within that department -- capture important aspects of disciplinary culture, this case may be illustrative of other (American) mechanical engineering

departments and the shared and controversial beliefs that one might expect to find. Perhaps more importantly, this conceptual framework - though not the particulars of the profession examined - may be useful in considering the scholarship of teaching in other fields of study.

The National Scene: Situating Pine's Mechanical Engineering Department within the Discipline

During the 20th century, the history of engineering education has been characterized by shifts from a craft focus to a scientific focus and back again. Before the Second World War, engineering education focused on applied, experiential training (Cunningham, 1986; Tribus, 1990). In the mid 1950's the terms "basic sciences" and "engineering sciences" entered the dialogue on engineering education, with curricular reforms that made engineering education more scientific and theoretical (Evans, McNeill, & Beakley, 1990). Pine University - a leading American research university with a highly ranked engineering school - built a solid reputation during this period of scientific expansion. By the late 1960's, the pendulum was swinging back toward practice, with requirements for design education being put into place - teaching students to think artistically as well as scientifically when creating new products and solutions to physical problems (Cunningham, 1986). Leading the field, Pine University developed an unusually strong design division. These tensions in how engineering itself is conceived and taught continue to manifest themselves in the educational beliefs of the faculty members at Pine University's mechanical engineering department. In many ways these tensions are brought into stark relief in Pine University's department because they have a larger and more active design group than most universities.

The University Context

Pine University, a highly selective private research university, draws students from around the country and the world. It has an unusually large proportion of graduate students. The campus has a residential character; almost all the undergraduates, a large percentage of graduate students, and a substantial number of faculty live on campus. Ethnic minorities and foreign students make up half of the undergraduate population and almost the same percentage of the graduate population. Nearly all of its undergraduates fall within the traditional 18-24 year old age range. Over half of the undergraduates, and an even larger percentage of graduate students come from outside the state.

Pine is decentralized in its governance and administration. Colleges and departments autonomously manage their own affairs with few requirements from above. There is a strong tradition of faculty governance, with the faculty senate a key decision-making body. Conversations with administrators reveal a respect for faculty autonomy. Faculty seem happy with their authority within the institution.

Because undergraduate students must complete several core requirements and a number of distribution courses to ensure breadth in their studies, students in the engineering schools have a broad liberal arts education in addition to their technical major. These university requirements constrain the number of courses which can be required within the engineering major and make fulfilling accreditation requirements more difficult since students at Pine University take more liberal arts distribution courses than some of their counterparts at other universities.

The Mechanical Engineering Department

The mechanical engineering department at Pine University enjoys a high ranking among other similar universities and an exceptional academic reputation. Consistent with this high status, the department has a concentration of very experienced faculty. Full professors make up fully 60% (21 of the 35) of the department's regular, full time academic staff. Faculty exude a confidence and pride in the reputation of the department. They also seem free to experiment because of the credibility that comes with their esteemed positions.

The department is composed of three divisions - Thermosciences, Design and Applied Mechanics – each housed in separate buildings. Approximately 43% of the regular, full time faculty members are in "Thermo", 40% are in Design and only 17% are in Applied Mechanics. This study focuses only on the two major divisions, as the considerably smaller applied mechanics division does not teach any undergraduate courses, did not participate in the larger teaching project of which this study is a subset, and was discussed very little by interviewees.

The department graduates about 160 masters students, 60 undergraduates and about 30-40 Ph.D. students each year. They have a relatively high proportion (25%) of women undergraduates relative to other engineering departments.

As described in the preceding section, the history of the department is a microcosm of the development of the field of engineering during the 20th century. Until the 1950's, the department specialized primarily in "classical mechanical areas--of gears, of pumps and engines and stuff like that" in the then current model of engineering which was "very empirical and people just sort of did things by the seat of their pants," according to a senior member of the thermoscience faculty. In the 1950's Pine University's mechanical engineering department hired several engineering researchers who were well-known for bringing science to engineering. A well-respected computational, analytical research group in thermodynamics grew up. In the late 1950's and early 1960's, the department's design division began to form. This new design division was known for fostering creative thinking in its students, in recognition of the divergent thinking required to design innovative new products. Faculty in a special program in product design collaborated with the art department, modeling the program after architectural education programs.

There has been conflict over the years between the two divisions, acknowledged explicitly by both sides. The thermosciences division has its roots in science and prides itself on its rigor and association with "hard" science. The design division has its roots in art and is often labeled the "soft" side of the department. These intellectual differences, compounded by a lack of interaction and geographical separation, pose challenges for the department.

The thermosciences division, exemplifying the norms of scientific engineering in the academy has, until recently, enjoyed a higher status and greater power within the department than the design division. The balance of power between the two divisions, though, has shifted in recent years. The profession is now paying more attention to the cognitive and social processes of design than it has in the past couple of decades. Revised accreditation standards reflect this new emphasis on design experience. Students, also, are becoming increasingly interested in manufacturing, enjoy the design process, and are enrolling in the design division programs in larger numbers.

Pine University's mechanical engineering program is accredited by the Engineering Accreditation Commission (EAC) of the Accreditation Board for

Engineering and Technology (ABET). Thus, the mechanical engineering major has been designed to meet the ABET requirements and the Pine University school of engineering requirements. The major, combined with the university-level curriculum, creates a rigorous and full program which students must schedule carefully to meet all of their degree requirements.

At the time of this study, the department was engaged in an active and, at times, heated debate, over the requirements for the mechanical engineering major. The thermosciences and design faculty seemed deeply divided over the representation of their areas within the depth requirements for the major. As a result of "gridlock" and at the suggestion of influential faculty members, the chair appointed a committee of eight faculty members, representing all three divisions, to do a "clean-sheet-of-paper" redesign of the undergraduate curriculum. The committee started from the ground up, first defining the broad goals of the program and then outlining a program to fulfill those agreed-upon objectives. At a general level, the department agrees on its goals, but when making hard curricular decisions, differing priorities emerge.

Shared Beliefs about Teaching in the Field

There are some general beliefs related to teaching that are shared across the department. First, the faculty generally see their students as "smart." Selective admissions policies mean that they are working with very academically apt and well-prepared students.

Student difficulties are attributed to differences in cognitive styles or to a lack of experience with "tinkering," rather than to general intelligence or lack of motivation. Many – although increasingly, not all - mechanical engineering students have gravitated to their field because they "like to put their hands on things and build." (AD) Thus, many have a good physical understanding of the world and may have difficulty when dealing with abstractions that they cannot see or touch. Other students, though, may excel in the abstract world, solving mathematical problems on paper proficiently and have more difficulty developing physical intuition. Students with either type of strength may have difficulty making connections between the physical, concrete and the abstract theoretical world.

The faculty also acknowledge that their students have a variety of career aspirations. Some of their undergraduate students will go directly to industry as professional engineers or seek an advanced degree in engineering. However, a significant proportion of the students will go on to careers in law, business management or medicine, using their BSME as a liberal arts degree. Thus, the faculty seek to offer a program which serves these various student goals.

The department agrees that students should learn "fundamentals specific to mechanical engineering" which includes "basic principles and methods for modeling, analysis, and synthesis of mechanical systems." This understanding is based on a solid grounding in mathematics and sciences and "should be broad enough to include applications to, for example, thermomechanical, electromechanical, and biomechanical systems." In addition to grasping the fundamental principles and content areas, students are expected to "be familiar with the full range of processes involved in product development and manufacturing." Lastly, the faculty wants students to be sensitive to their responsibilities in society and able to communicate effectively with less technically proficient colleagues (Goals of the "Pine University Undergraduate Program in Mechanical Engineering,

Undergraduate Curriculum Committee Draft). Most of the faculty I interviewed mentioned the importance of developing students' oral and written communication skills--being able to present a solution to a problem and explanation of the rationale or methods. These general goals are consistent with the curriculum as it currently stands, the college of engineering goals, and the ABET objectives. Thus, there is little contention at this level.

However, while they agree on their general goals, debates about changes to the actual courses required for the major illustrate that there is not agreement over the relative emphasis on these various goals. While some of the departmental acrimony may be politically motivated -- based on private interests and resource allocation concerns -- the root of the differences seems to be intellectual.

Across the seven focal faculty, there were differences in how they conceived of engineering itself - whether the focus was on creating vs. assessing creations and, similarly, on whether engineering is primarily an art or a science. In general, the design division emphasizes the larger process of product design more than the thermosciences division, which is focused more on the "fundamentals," and the teaching of analytical skills.

In the next section, I present a summary of two cases of young faculty--one from each division--and their descriptions of the courses they teach as illustrations of some of these points of difference between faculty in each of the divisions. The cases of Ned and Kevin were selected because they illustrated some of the key tensions within the department and perhaps the discipline as a whole, as can be seen in the discussion of emergent themes following. They were matched for similar levels of teaching experience and tenure in the department.

Ned Lawson

Ned Lawson is an assistant professor in his second year in the department. Ned specializes in micromechanical devices and was hired to teach courses on sensors. He focuses on the creative side of "making things," with a view of engineering as an artistic process requiring divergent thinking and a combination of social and technical awareness.

Ned has students study various types of sensors in use around them, focusing on hands-on experiences because "what constrains you when you're designing isn't the stuff on the data sheet, but the stuff that isn't well represented there. . .If you look and pick a sensor up, you can see how big it is, they can kind of feel whether it's made out of crummy plastic or really expensive metals." On the midterm exam, he pushes students to go beyond what they have encountered in the homework, "forcing them to try to figure something out that they haven't yet seen or heard." His students' final assignment is a paper in which they "invent something and write up the kind of invention disclosure that you might present to an investor." Ned, envisioning his students as future product designers, wants to "give students the tools. . . to be able to design around a sensor." A critical part of that design process is understanding that many new designs involve applying existing technologies in new ways to pre-existing products. So, he wants students to learn about the current development market and the "performance characteristics of typical sensors, cost issues, which ones are cheap, which ones are really expensive . . . . and [how to] pick the right one and then properly attach it to their system." He focuses on processes of design, divergent thinking and creative synthesis of new ideas. Ned explains that students struggle with the ambiguity and open endedness of the final paper he

assigns, but that his assignment is a realistic example of the ambiguous and ill defined problems they will face outside of the university.

Kevin Harrison

Kevin Harrison is a thermoscientist in his first year at Pine University. He studies heat transfer in nano-structures and teaches heat transfer courses. Kevin focuses on ensuring that the things made by engineers work properly, using mathematically expressed scientific laws as the foundation for analytical processes of solving physical problems. Kevin hopes students will learn the basic principles and laws of heat transfer as the basis for problem solving. He emphasizes having an "intuition" or a feeling for a problem to be able to give a quick response even when you are away from your desk. "I emphasize very strongly the ability to write down [an approximate solution] in a few seconds within 20 to 30 percent without having to derive the precise result."

His focus, then, is on students' analytical abilities, converging on a correct solution both through intuitive estimation and, secondarily, on precise mathematical calculations. In his lectures, he generally starts with a "sketch of the physical problem . . . And I discuss the physical problem and then derive the approximate solution that I discuss, typically. And then derive the exact solution. And then apply it, if there's time, to a practical problem." Students practice the analytical problem solving process in homework problems and in similar exam questions. Unlike Ned, he tries to make the exam questions less ambiguous than homework problems, "the exam typically defined the problem reasonably well whereas the homework left some things to be assumed." Kevin is concerned that students are able to take the laws and principles they are learning and apply them in a variety of contexts. "If you can only apply it in the context of class or in the context of a given problem, then you haven't learned very much."

These two engineers emphasize different aspects of what engineering practice is about. These different orientations underpin differences in Ned's and Kevin's goals for students. The assignments that Ned and Kevin pose students are consistent with their different orientations to engineering work. Both of these faculty want to prepare students for the realities of workplace situations they may face as mechanical engineers, but they take different angles on the anticipated challenges.

Emergent Themes Across all Focal Faculty Members

What is engineering? Differing conceptions of engineering work itself lie at the heart of how these faculty members conceptualize their scholarly work. All of the faculty are oriented toward preparing students for the real world demands they will face as engineers. They justify their curricular choices according to their vision of what engineering practice is. Many of the differences between the two divisions within Pine's mechanical engineering department, though, stem from attention to different aspects of engineering practice in the workplace.

Applied artistic creation vs. assessing and explaining creations scientifically

All of the faculty assert that at the most fundamental level, engineering is about creating something new. Some faculty (particularly design faculty) focused more on the process of getting to the three-dimensional product, while others (particularly in the thermosciences) talked more about the data which proves that the new, three dimensional creation works effectively. The design faculty described

aspects of the creative process, including sketching and team work. Ned's emphasis was consistent with that of his design faculty colleagues.

The thermoscience faculty, exemplified by Kevin's analytical focus, emphasized the type of skills and questions that go into determining whether an interesting idea will actually work. One of his colleagues explained what he teaches: " 'How big does it have to be for whatever its function is? What do you have to make it out of to make it strong enough?' Those type of things would be your analytical questions. . . . [You can have a great idea but] the whole thing is predicated on, 'Am I going to be able to get enough flow through this space?' So the first thing I'm going to do is analyze that, and say, 'Well, no, I can't get enough flow through that space. And so, this isn't going to work.' " (JF)

These differences in foci on different aspects of engineering may be best explained by noting that engineering as a profession borrows from various disciplines in order to successfully "make things that work." "Thermosciences has its roots in science and design has its roots almost more in art," according to faculty members in this department. Members of the thermosciences faculty explained the importance of a scientific background in areas like electronics and fluid mechanics:

> It's engineering science--its what they need in order to be able to analyze something that they might want to build so they can make sure that its going to stay together--going to fly . . . . The ultimate goal of a scientist is to understand why things behave the way they do. From some simpler principles. The ultimate goal of engineers is to make things. But, in order to make things, you need to know how things work. So you need to have a science base in order to understand things. (BS)

The design division, on the other hand, teaches students the artistic and social side of engineering. The former chair of the department explained:

> [Students coming out of courses in design] have a lot more artistic exposure--cultural awareness, let me put it that way. . . . What kind of products do people really need? Why do they like things that are like this?. . . . It makes the engineering programs more useful to people. (BS)

A senior faculty member in design expounded on his own "laws" of design which are social and artistic in nature rather than mathematical or scientific:

> We have three laws of design. And this is mimicking my thermosciences friends who have the three laws of thermodynamics. So theirs. . . have their roots in physics and our three laws have their roots in practice. . . . The first law is that engineering design is a social activity [rather than a solitary individual doing something alone in his head]. . . . The second law of design is that designers require ambiguity. . . . And the third law is that all design is redesign. . . its the sense that don't ever let yourself believe that you have a blank sheet of paper, a blank canvas. (LM).

The thermosciences division, with its science foundation, is also more theoretical in its orientation than the design division. As the previous quote suggests, the design division sees their work as tied closely to practice. A design division professor who also conducts research on how engineers do design highlighted this difference between the two divisions:

> The applied mechanics and thermosciences groups, in my view, essentially start with a set of theories and try to do two things. Expand the theory and make some application. The applications are usually secondary. The primary goal is to expand the theory. The design community is much more driven by, if you will, reality--to what's going on in the world. Products need to be built. Manufacturing needs to be done. The management of information to do those things acts as one of our major concerns. And lacking a theory, in design, it is broadly seen as a pre theoretical field. .(LM)

What is taught?

Synthesis vs. Analysis

These emphases on different aspects of engineering work play themselves out in the curricular and pedagogical choices of the faculty. Faculty in the design division look at the creative side of design work and emphasize synthetic thinking in their courses. The thermosciences faculty pay more attention to the analytical work of engineering, so they teach analytical thinking.

While the contrasting terms "synthesis" and "analysis" capture some of the important differences in focus between the divisions, not all faculty were equally comfortable with those particular terms. Some experienced faculty members in this department refer to synthesis and analysis comfortably and explain them and their roles in the curriculum articulately. From the design division:

> Analysis is a reductionist activity--it means taking something that exists in a complex form and saying, 'what are the essential elements to figuring out how it works?'. . . . Whereas the design issue is much more of a divergent activity, saying, 'O.K.. I want to create something in this room that provides a central focus and is a convenient means for people to sit around it and I'm not specifying what it is. And it has these other attributes'. . . so it's a much more expansionist activity. Now they complement each other because once you come up with this whole spectrum of possible solutions, you need to start doing some analysis to see which are realistic. . . . .so it ends up being this sort of cycle of expansion and then honing it and getting these specific dimensions or verifying dimensions used on analysis and then maybe going out again. (ST)

From the thermosciences division:

> [Analysis is when] you have a defined problem that you need to know the answer to, to design your "thing." A good example would be: I'm going to have this part here, and it's going to stick out here like this, and it's going to have some weight on the end. And if it bends too much, the whole machine is not going to work. So, we teach analytical

> techniques that will allow you to figure out how much it bends. That would be an application of some differential equations and solving them. Then you'd be able to tell what the shape of this would be under this load. . . . We teach a lot of analytical things in the Fluid Mechanics [courses]. The easiest view of the synthesis is: taking all this that you're doing, putting it together, and designing something. . . .to fill a need. . . . I think a product is needed here [like a product which will support a weight at a distance]. I have to put together all I know in order to solve that need--to design a solution. (JF).

Other faculty, though, were less comfortable with this distinction. One senior member of the thermosciences division, in seeking to recognize the interconnectedness of these thinking skills, was hesitant to use the words at all because the distinction between analysis and synthesis is "artificial." Rather than encourage a portrayal of these skills as separate, he argued that "there is some of [each set of skills] in each of the things that we do." Again, most of the faculty do see that both sets of skills are essential for engineers. Increasingly, the department is seeking to develop their educational program to better integrate the differing strengths of the department.

Young faculty like Ned and Kevin are less familiar with the terms of the discourse than their more senior colleagues. When asked to explain the terms, they did not clearly express the analytic/synthetic distinction and instead treated the two types of thinking together as representing, in a general way, "the ability to take the information and apply that in context." (KH) or as what it takes to "be a confident engineer." (NL).

However, although they were not as fluent in the particular terminology which shapes the dialogue in the department, their pedagogy was generally consistent with the split between the divisions. Ned's assignment requiring students to "invent" a new product that incorporates a sensor is a prime example of a synthesis or, a whole made up of parts of elements put together. Kevin, on the other hand, focuses on students learning to analyze a problem, or in dictionary terms, to be able to recognize the basic elements in a complex problem, to solve mathematical problems with equations, and to examine the relations of variables.

These new academics, like their elders, though, see that students need both analysis and synthesis. Kevin notes, "There's a problem or a challenge for us in that our courses loose any sense of creativity. They're strong analytically and they lose -- I think it's something that we have to work at to bring some element of design to thermosciences." Ned also refers to the analytic side of engineering work when he emphasizes, like Kevin, that students need to be able to provide quick estimates in the field based on simple, short-cut calculations.

Divergentt vs. ConvergentThinking

Related to the analytic/synthetic difference in emphasis between the two divisions is a tendency toward either convergent or divergent thinking. Thermosciences faculty, with their analytical, scientific orientation, expect students to reduce complexities within problems to converge on a single answer. Kevin's description of the process he uses during a typical class period, quoted earlier, is an excellent example of convergent problem solving.

Design division faculty, though, tend to start with a problem (a set of needs or constraints) and ask students to think up many different possible solutions. As an experienced design division faculty member explained,

> They are asked to do not traditional analysis problems where you've got this thing and you've got to figure out how much force can it carry. We're saying [instead], "We want to do task X, for which there could be as many solutions as there are students in the class."(AD)

In his course, for example, he requires that students design game-playing robots which are able to negotiate certain rules of a game, such as following a line or seeking darkness like a cockroach. Students entertain many possible solutions in the process of creating a unique design. Design as a process is "very under constrained" (ML) and learning to effectively pursue many divergent possible solutions is the key to creative success in design. Without it, "you will produce mundane, routine products." (LM). Louis Magee gave an extreme example of how he emphasizes creativity and the need to devise multiple solutions to the same problem:

> One of the exercises we have them do--we give them a whole assignment. . . . At the end of the first week, we're going to tell them to throw away the design. I mean, literally, they're going to build something and we're going to say, "That's the trash can. Put it in the trash can. Free yourself from your mental set that you've just solved the problem in the only way that it can be solved. And now think of 20 other ways to solve the problem." (LM)

How to teach engineering?

Ambiguity vs. Defined Parameters

Focusing on convergent vs. divergent thinking may be just one striking instance of a larger attitude toward ambiguity. As the two divisions implement their teaching based on their differing strengths and foci, they set up the constraints of student's problem solving exercises differently. Faculty in the thermosciences division, tend to seek to reduce ambiguities. Kevin described how he constructed his midterm and final exams saying he "typically defined the problem reasonably well whereas the homework left some things to be assumed. . . . I didn't always manage to achieve a problem whose solution was by far best achieved using a given approach. But that was typically my goal. Particularly in exams." He argued that the "stakes are higher" on exams so he wanted to reduce the ambiguity in those tense situations.

On the other hand, design division repeatedly told me that problem solving in the "real world" was full of ambiguities, and they construct their assignments to prepare students for those realities. For example, Ned explained that students found the ambiguity of his final assignment challenging, but that it was essential that students learn to work in such environments because, "that's the way life is. There's not too many perfectly defined problems that you get to work on in this world. Often they are undefined or ill defined." (NL). He also wrote his midterm examinations so that they were similar to the homework assignments, but unlike his colleague Kevin, he "sort of push[ed] the envelope of what they've heard specifically. Forcing them to try to figure something out that they haven't yet seen or heard. "

Modes of instruction

Most faculty in both divisions use lectures as a way of conveying information during class time, relying on chalkboards and overhead projectors to visually illustrate important points. Faculty use lectures and homework assignments to give examples of what they are teaching. The thermoscience faculty, in particular, talked extensively about giving examples. In the case described earlier, Kevin explained how he works with examples in his courses and relies on them to illustrate his points.

Some faculty also rely heavily on hands-on contact with actual physical artifacts by doing demonstrations with objects in front of the class, passing around small motors or other objects, or encouraging students to come to the front of the room to manipulate a piece of demonstration equipment.

Kevin seemed to emphasize the hands-on experience less than the other faculty. Instead, the heat transfer course he taught first and described in his first interview was more theoretical and abstract than other courses. He referred to hands-on projects more in his second interview as he described a course he taught later in the year. In general, because engineers work on making real, three-dimensional things, these hands-on opportunities are important to these faculty. Several academics pulled gadgets off shelves and out of boxes during our interviews to demonstrate examples of things we discussed.

Laboratories vs. Projects

Laboratories and design projects also offer opportunities for hands-on work. Lab courses are a common mode of experiential learning in the thermosciences while project courses are their counterpart in the design division. Laboratory projects in the thermosciences are, as discussed above, more close-ended than the design projects. A thermoscience faculty member explained that he puts boundaries on the lab projects because he wants to ensure that students practice the particular skills that they are taught in his class, so he defines the problems for them.

In the design division, design projects replace laboratories. In some of the project-driven courses, students spend more than half of the course working in teams of 3-4 students on a final project. In one course, for example, students build game-playing robots that compete in a tournament at the end of the term. These projects offer opportunities for students to practice defining problems and draw together what they know to design a solution.

The projects also offer a reason to learn new things in order to improve their projects or solve a problem they have encountered while working on them. Thus, there is immediacy to the knowledge they are gaining which is very motivating and exciting to students.

Finally, design division faculty emphasize that projects are an occasion for teaching students cooperation skills--to learn to work together effectively (AD, LM, ML, ST). Thus, the process of collaboration on engineering tasks is taught, practiced and reflected upon through group projects. Several faculty noted that when students come in, even as graduate students, they often have little experience in coping with "teaming" so it is common for the faculty in design classes to have students do " a series of graded design experiences" early in the term (LM). "It's like doing calisthenics. . . practicing" the group process skills with relatively easy design tasks so they can successfully handle a large, complex project later in the term and in their careers (LM).

New Plans for Projects--Perceived Advantages and Barriers

Traditionally project courses have fallen into the domain of the design division faculty, and, as such, typically have not fully utilized the content that students have learned in their thermoscience courses. At the time of this study, plans were being made – in connection a curriculum revision – to put the design process at the center of the department's curriculum, with increased attention to integrating both mechanical and thermosciences content into the projects through teaching collaborations among faculty across divisions. Thus the department has proposed to revamp its courses that deal primarily with "consolidated blocks of disciplinary knowledge" by coupling them more closely with the projects students will be doing in concurrent courses.

Many faculty pointed out that students suffer from the separation of science and art, analysis and synthesis and, foundational knowledge and the design process, within the department. Faculty in both divisions spoke favorably of dissolving the dichotomies within the department through greater cooperation between the divisions. They saw a project-centered curriculum as having potential for creating an integration of the various content areas and engineering skills. However, all faculty had some reservations about such a curriculum, though the nature of these reservations varied by division.

Several faculty who are experienced with project courses noted how much time and effort go into a successful project course, particularly in individual attention to groups. This staff time may be hard to come by in a department where faculty already cite time as their biggest constraint.

Design division faculty also note that when the content of lectures and assigned readings doesn't perfectly match what a student needs in a given week to work on their project, the motivational benefits of projects are lost. Matching the lecture material in a project course to students' progress on their projects can be extremely challenging.

While design faculty spoke about the practical constraints, faculty in the thermosciences have different objections. The faculty I interviewed in the thermosciences profess to agree with the idea of teaching their material through project-driven pedagogy, but are hesitant because they believe that their material is less amenable to that teaching approach. Kevin expresses that hesitation: "you need more groundwork before you can play in the thermosciences." A senior colleague of his also explains that the hierarchical nature of the knowledge they teach in the thermosciences means that students can't just pick it up "as needed" in the context of doing a project.

Design faculty who are experienced in project pedagogy also struggle with the dilemma of allowing students with little background knowledge the opportunity to engage in the "interesting" high level, creative design work which, in the past, had only been accorded to graduate students. One member of the division, who has been active in an engineering reform project, has devised a solution to the dilemma. He explains how he redesigned a year long graduate sequence into a one term undergraduate course:

> The conclusion I came to was that we needed to have them learn about the same material but work at a higher level. To not work at the lowest level of technical detail. So, for instance, in the graduate course the students learn how to design the circuits that would drive the motors.

> They learn how to write, from scratch, all of the software that would be necessary to drive the motors. In the undergraduate course, we give students circuit boards that has a motor driver on it, and we show them how to use that existing motor driver - how to connect it up to a motor, how to decide whether the motor will work with that particular set of hardware, but not the details of how to design the motor drivers circuit itself. On the software side, we give them software modules that will drive the motor. It will go forward, go reverse, change speeds. Then we give them a project where they need to use a motor to go forward or backwards or change speeds. They have this piece of hardware that will drive the motor, and they have this piece of software that will control it, but they still have to put the physical things together, and they still have to write the higher level software that implements the strategy if you will. . . . The goal is to give them the same sort of satisfaction and feeling of accomplishment that the graduate students get out of building these projects, and provide them with a big enough toolbox that they can actually build these things in the span of one [academic term]. (AD).

A colleague of his, both in the division, and on the educational reform project, notes that some faculty in machine design at other universities also believe that students need a lot of foundational knowledge before they can "play" but that she subscribes to a different belief. "I don't believe in that philosophy that says you've got to learn this whole big chunk and then you can do something creative with it." People must always learn new material as they encounter new projects and problems in the profession "they are going to have to be dealing with content continuously because they don't know everything," so she wants them to start working in that environment from their first days at Pine University.

Thus, faculty in the design division who successfully implement project centered design courses seem to have a different philosophy about the relationship between the content of a course and the overall process of designing and doing creative projects than do their colleagues in the thermosciences division.

Roles of teachers

Lecturers vs. Facilitators

Some of the faculty, including the thermosciences faculty, spoke only of their role as that of "teacher"--they had some difficulty in choosing a metaphor or speaking of their teaching roles in other ways other than conveyors of information or models of engineering problem solving. Faculty experienced with project pedagogy in the design division, however, spoke at more length about their roles as instructors, noting how their role changes when their primary pedagogical approach is having students working together in teams on projects. Al Drummond summarized his role as "the ultimate advisor," referring to the ways in which he consults with and offers guidance to project teams in both his undergraduate and graduate level design classes. Sandra Tisdale also describes her role as a "facilitator or a mentor" and explains:

> "For myself and for the TA's to be . . . walking around, seeing where [students'] questioning is, maybe asking questions. . . . this is a really

> different role for an engineering faculty member to play. . . . I see us as facilitators of helping them to learn group process as well as learning the stuff." (ST)

Student difficulties

Applying old knowledge in new contexts

The faculty in both divisions discussed the difficulty students can have with applying knowledge in a new context. In psychological terms, this is the classic problem of transfer. The thermosciences faculty, for example, explain that students are able to solve complicated mathematical problems in context-free, textbook problems, but when it comes to recognizing and abstracting the problems to new situations, students have difficulty:

> I think it's applying their math to things that arise. . . in a physical situation. . . . And if you assign them another problem. . . . If they follow it through, it leads to a simple differential equation. . . that they've solved many times in Differential Equations class--the simplest possible differential equation--then they go to pieces. They all are "A's" and "B's" in Differential Equations class. They were able to solve much, much, harder problems than, for example, we might lead them in to. Yet, [in the math classes, the problems] were just posed as, "X" plus "derivative of X" plus "C" is equal to "B," or something like that. . . . And then they solved it. Now, they take a physical situation and reduce it down, and it gets into an equation--and they can't solve it any more. (JF)

These thermosciences faculty explain how they try to give a lot of examples to help student see problems in various contexts. Kevin Harrison believes that the connection between the mathematical understandings and the physical situations will come about by building their intuition and "feeling" through learning to do "back of the envelope" estimates. He thinks that they can get so lost in precise mathematical calculations that they forget how the equations they are using are related to the actual physical circumstances of the problem.

Students' failure to transfer the analytical tools they learn to new contexts is also recognized by the design division faculty who note that design projects sometimes fail because students do not apply what they have learned of analysis to their design projects (ST).

While the design faculty share the realization that it's more difficult to solve embedded, contextualized problems, their response to the problem is different than the thermosciences faculty. While the thermosciences division faculty start with the skills and later ask students to apply them through examples, the design division tends to start with the context--the project--and demand that students learn the skills that they need in that context. These contrasting approaches are consistent with two broad theories of transfer, which have applications to a variety of professional education settings. (see Eva, Neville and Norman, 1998).

Ambiguity

The design faculty's educational beliefs and the demands of their approaches expose students' weaknesses and difficulties in some areas that are not highlighted by their colleagues in the thermosciences. Most students, for example, struggle with the lack of structure in the design division's open-ended projects and assignments.

Through years of schooling, students are accustomed to knowing very clearly what their teachers expect of them yet, "If you're doing a project, you're never quite sure, 'Am I getting what they want? What do they want? How do I measure up?'" (ST). Because part of the design division philosophy is to develop students' expertise in situations without clear cut parameters, the faculty consciously seek to find an acceptable balance between offering feedback and encouraging students to struggle on their own.

Divergent thinking

Faculty in the design division also note that their demands for divergent thinking are difficult for students to successfully meet. Students often do not have a lot of experience with brainstorming and creative thinking and must be taught explicitly to overcome their desire to narrow down their options too soon.

> The hard part in design is getting students to realize how many options they really do have. Because there is a very strong tendency to come up with *A* [single] solution and then just stick with it and then just keep sort of patching it and sculpting it and crafting it because new information comes in and you learn more while you fix your existing solution some more. What you want people to do is to start with 10 solutions and keep all 10 of them going for awhile. And then gradually maybe narrowing it down to 5 and 3. That's a lot of what design's about. (ML)

Teaming

Finally, design division faculty, with their emphasis on teaching students the social aspects of design, find that students often have little experience with and few skills in successful teamwork. Students generally need feedback, practice and reflection on their experiences to develop effective group process, communication and cooperative skills.

Summary of Key Themes in Context

The mechanical engineering department at Pine University is fractured between its two major divisions--thermosciences and design. There are significant social and intellectual differences between the divisions. These scholarly differences manifest themselves in varying pedagogical philosophies and practices, including their discussion of goals for students, teaching practices and their interpretation of students' difficulties. Those who are design and art-oriented, also tend to see learning the skills of synthesis and divergent thinking as primary goals for students. They assign ambiguous problems and team projects. These faculty find that students have difficulty coping with those loosely structured problems and working in teams. More scientifically oriented engineering faculty value analysis more highly. They expect their students to master analytical thinking that converges on a right answer, and give them structured problem sets and traditional science laboratories to help them hone these skills. These faculty find that students struggle with applying principles to new contexts.

These differences and tensions between the two divisions in Pine University's mechanical engineering department are an illustrative case of larger controversies within engineering education, as described in the earlier discussion of the history of the field. In a review of design in engineering education, the debate over design

versus analysis "seems to occupy the top drawer of a Pandora's box of controversial curricular matters, a box often opened only as accreditation approaches."

Significance

This study of educational beliefs situates academics' educational goals, choices, practices and analysis of student work in scholarly differences about the field of engineering. While the department of mechanical engineering at Pine University can agree on its goals for students in general terms and its faculty share many similar commitments and practices, closer analysis illustrates some of the differences in beliefs. The differences among scholars within the department seem to fall along some of the same lines as the larger debates and changes that have marked the recent history of the engineering profession.

This study is unique in four main ways, each with importance to understanding teaching in higher education. First, there has been little attention to educational beliefs about the discipline, despite the fact that most academics identify most strongly with their disciplines or fields of study. At the primary and secondary levels, there has been more attention paid to the disciplinary aspects of teachers' knowledge and beliefs (Calderhead, 1996; Shulman & Quinlan, 1996).

At the higher education level, Lee Shulman (Shulman, 1993) and Alan Jenkins (Jenkins, 1996) have separately argued that teaching improvement efforts should be situated in scholarly (traditionally disciplinary) communities. Research that can illuminate how teaching and disciplinary cultures, in particular, are intertwined may be helpful to educational (faculty) developers who work with academics and departments on the enhancement of teaching. Indeed, most educational development professionals already have a solid base of knowledge on the university context. However, they may have limited knowledge about the various subject matter clusters with which they work. They might particularly benefit from deeper understandings of the subtleties and tensions within disciplinary cultures. Thus, the results of additional discipline-focused studies could potentially be fruitfully applied in practice.

Third, research that has been conducted on discipline-specific aspects of teaching and learning (Biglan, 1973; Hativa & Marincovich, 1996; Lattuca & Stark, 1994), has tended to focus on differences between disciplines. Yet, differences within disciplines may lie at the heart of what Ernest Boyer (1990) called the "scholarship of teaching." Scholars make their reputations by contributing new knowledge, interpretations, paradigms, methodologies, syntheses or applications (Boyer, 1990). In short, scholars are known for the ways in which they diverge from or distinguish themselves from other scholars within their given specialty areas (Weiland, 1995). By focusing on teaching, this study has revealed some of the finer distinctions among academics within a field. When academics discuss the rationale behind specific courses and assignments, their comments illuminate different basic conceptions of their fields. Studies which devote attention to these differences among academics within a field may be especially helpful in constructing fuller pictures of core beliefs, goals, methods and teaching and learning challenges in each field. This perspective may allow researchers to better see the common threads of scholarly conceptions that connect faculty members' research and teaching work. Therefore, such further study may also help explicate the notion of the scholarship of teaching by illustrating the ways in which teaching reveals scholarly conceptions or, conversely, the way scholars' identities shape their teaching.

Fourth, this study has gone beyond most psychologically-oriented studies of teacher thinking, by situating individual faculty members within the context of a department, a university and a discipline. Contextual factors play an important role in shaping individual beliefs, choices and actions. As such, researchers of teaching and faculty developers need to become better at engaging with, understanding, studying and working with these contexts. Much remains to be done on this front. One of the major limitations of this study was that it focused on just one department in the field of mechanical engineering. Contributions to the literature would be stronger if based on studies carried out in more than one department. Another limitation is that the personal, professional histories of the academics - another important influence of educational beliefs - are not adequately addressed. Nonetheless, this study represents one attempt to investigate the scholarly dimensions of educational beliefs about the discipline while simultaneously grappling with some important layers of contexts in which the intellectual roots of teaching are buried.

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The author can be reached at:

Dr. Kathleen M. Quinlan

S2 014 Schurman Hall, Office of Educational Development

College of Veterinary Medicine

Cornell University

Ithaca, NY 14853-6401 USA

kmq1@cornell.edu

phone: 1 607 253 3767